ACTIVITY REPORT

November 2000

Natural Gas & Oil Technology Partnership

bringing department of energy national laboratories capabilities to the petroleum industry

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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Oil and Gas Recovery Technology Drilling, Completion, and Stimulation Technology Diagnostic and Imaging Technology	Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Oil and Gas Recovery Technology

Improved Prediction of Multiphase Flow in Petroleum Reservoirs

(Mobil, Unocal, UT-Austin, and PNNL)

Project completed.

Improved Waterflooding Through Control of Brine Composition and Other Factors

(BP Amoco, U of Wyoming, and INEEL)

Highlight:

- Core from five wells selected for laboratory testing.

INEEL is still waiting to receive cleaned core plugs from TerraTek, Inc., that were procured from the Utah Geological Society from five wells in the Greater Monument Butte region of Utah.

INEEL has shown that by injecting diluted reservoir brine into laboratory corefloods, waterflood oil recovery is significantly increased under certain conditions. Reservoirs and crude oils from the Monument Butte region fit preliminary screening criteria for applicability of the process. Fresh water is being injected along with produced brine commingled with the fresh injection water after breakthrough. This provides a potential opportunity to test the process in the field by controlling the locations where the commingled brine is used.

Water and oil samples were collected from the Monument Butte (MB) field near Roosevelt, Utah. Produced water was collected from six wells in the field. Five of the wells had very low water/oil ratios (no water breakthrough from injection wells), and one well had a higher water/oil ratio (breakthrough had occurred). These water samples collected from the MB field are being analyzed to determine the composition of the formation brine and injection water. Laboratory corefloods using MB crude oil, MB sandstone, and simulated MB brine are planned to ascertain the applicability of modifying the injection brine to improve oil recovery of the waterflood. Oil samples were collected from two different wells. While at the field office, project researchers discussed field history, current operational practices, and field economics with engineers and field personnel from Inland Resources, Inc.

Cores are being prepared to determine the scalability of the process from small laboratory cores to larger cores and eventually to a field-scale.

Final results from the University of Wyoming indicate that the epoxy used at the INEEL does not affect the wettability or imbibition of oil/water systems. This information is important because previous (and future) coreflood results from the INEEL were obtained using epoxy-coated cores.

University of Wyoming subcontract was awarded.

Development of a New-Generation Petroleum Reservoir Simulator

(BP, Chevron, Conoco, Cray Research, IBM, Landmark Graphics, Schlumberger-GeoQuest, Scientific Software-Intercomp, Texaco, Unocal, UT-Austin, and ANL)

Previously, ANL reported on performance of our compositional simulator on a cluster of PCs. (See column “PII-300 (old)” in the tables below.) The particular case presented was a simulation of a three-component model that simulated 100 days of gas injection into a homogeneous reservoir. The reservoir contained two wells, an injector located in one corner and a producer installed in the opposite corner. The initial conditions and production scheme were specified such that gas/oil/water were all present during the entire simulation, but water was immobile. The grid dimensions used in the simulations were 16×22×8, or 28,672 gridblocks and 229,376 unknowns. In order to carry out the parallel simulations, the domain decomposition is done in one dimension in the y-direction to decrease communication between processors.

Using the simulation, the team further investigated some details of the communication software (MPICH—a portable implementation of MPI from ANL) to make the interprocessor communication as efficient as possible. This is achieved by tuning the P4 socket buffer size. MPICH has an environment variable, P4_SOCKBUFSIZE, which sets the communication window size in bytes during TCP communications. This variable is set to 4096 bytes, unlike 7680 bytes in the previous runs. Also, the operating system (OS) in the cluster was upgraded to RedHat Linux v6.2 from v5.2. These new simulation results are also listed in the following tables as "PII-300 (New)." The same runs were performed using a second cluster consisting of dual 400 MHz Pentium Xeon PCs. These results are also reported in the tables. The dual processors in each box share the same memory bus and also performed very well after the new OS upgrade and communication tuning.

According to our observations, the single most important tuning parameter is the P4 socket buffer size for PC clusters. We observed that the total execution time is decreased several times when 16 or more processors are used with the tuned buffer size compared to the untuned system.

Table 1: Total Execution Time (Seconds)

No of CPUs	PII-300 (old)	PII-300 (new)	PII-400-Xeon (new)
1	992	961.2	611.4
2	457	439.2	278.5
4	231	218.2	139.4
8	119	111.4	72.0
16	82	63.8	46.2

Table 2: Speed-up (times)

No of CPUs	PII-300 (old)	PII-300 (New)	PII-400-Xeon (New)
1	1.0	1.0	1.0
2	2.2	2.2	2.2
4	4.3	4.4	4.4
8	8.3	8.6	8.5
16	12.1	15.1	13.2

Fluid Identification Acoustic Logging Tool

(BP Amoco, CGG, Chevron, Conoco, Landmark Graphics, Mobil, Schlumberger, Shell, Smedvig, Texaco, Unocal, Ward Petroleum, Western Atlas, and LANL)

Highlights:

- Latest results presented at the NGOTP meeting.
- Developed novel method for detecting suspended particles inside the resonator.
- Completed electronics circuit design for real-time monitoring of fluids

An up-to-date discussion of the present status of the Acoustic Fluid Logging Tool was presented at the Partnership meeting held in Houston, November 14. The presentation generated a lot of interest, especially in the acoustic phase separator aspect of this project. Several participants at the meeting enquired about possible new applications of this technology.

LANL developed and presented a new concept and preliminary results for the detection of suspended particles. This technique was developed in response to inquiries by last year's participants of the Partnership meeting. In a simple procedure, the existing resonator system can be modified to enable the detection of particle size and concentration in the flowing fluid.

The electronic circuit for real-time monitoring of fluid was developed and successfully tested in the lab. This circuit needs to be further miniaturized and tested under more stringent conditions.

High-Resolution Reservoir Characterization Using Seismic, Well, and Dynamic Data

(BP Amoco, Chevron, Exxon, Oxy, Phillips, RC2, Texaco, Western Geophysical, Texas A&M, and LBNL)

Highlight:

- Article submitted to journal.

LBNL continued analysis of partitioning tracer data from the Hill Air Force Base in Utah. An extensive set of partitioning tracer data was used to infer the permeability in a test cell. We submitted an article describing this work to the *Journal of Water Resources Research*.

Preliminary work has begun on modifying the streamline approach to account for capillary effects and diffusion. A review of the literature indicates that the asymptotic approach, the basis of our inversion algorithm, may be extended to situations in which diffusion is present.

We have begun to examine a set of time-lapse seismic data provided by Chevron. In conjunction with these data, we also have pressure, tracer, and water-cut observations. We are in the process of setting up a reservoir model for simulation purposes.

Measuring Sucker Rod Pump Parameters Downhole

(BP Amoco, Harbison-Fischer, UT-Austin, and SNL)

Highlights:

- First test of prototype electronics completed.
- Video capability added to transparent sucker-rod pump.

The first test of the completed prototype electronics was conducted.

Unique video capability was added to the transparent laboratory sucker-rod pump in Austin, TX. The camera rides up and down with the plunger and allows zooming in on the traveling valve. The video is captured in sync with the data measured allowing one to pick data points and display corresponding images. One can also step through the images watching the changes in measured parameters. This capability has verified the opening and closing of the traveling valve at the times predicted based on thermodynamic analyses of the compression chamber pressure.

Assembly of the prototype downhole instrumented pump for testing in Austin, TX, has begun.

Formation Logging Tools for Microboreholes (DeepLook, Texaco, and LANL)

Highlights:

- Microhole resistivity tool study completed.
- Continuation proposals prepared and presented.

Under contract to LANL, the Cedar Bluff Group, a company specializing in resistivity tool development, completed a study of the advantages and technical challenges of making formation resistivity measurements in microholes. Several advantages were noted including the capability of moving to higher measurement frequencies (hence resolution for induction logs) and the reduction of uncertainties normally associated with resistivity measurements in commercial-size wells. Challenges include the reduction of transformer size for the electrode type resistivity tool and the reduced rigidity of microhole resistivity tools if they were to be made using conventional designs.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling (Mobil, Schlumberger, UT-Austin, and SNL)

Highlight:

- Completed first version of the coupled IPARS/JAS3D code.

SNL completed a first version of the coupled IPARS/JAS3D code, which includes dynamic updates to both porosity and permeability during flow simulation. Dynamic permeability updates during coupled flow simulation and geomechanical deformation modeling are extremely important as they serve to damp the impact of dynamic porosity changes thus producing results that should be more physically accurate. Once JAS3D has computed the volume strain in an element for a given time step, it then post-processes this strain to come up with new values of porosity and permeability that are then passed to IPARS for use in the next flow time step.

Much of recent work centered on comparing results from four simulations. The basic model problem was identical in each simulation. However, the simulations differed as follows:

Simulation 1: flow simulation alone (porosity and permeability assumed fixed throughout the simulation)

Simulation 2: coupled flow and geomechanics with fixed permeability and time-dependent (changing) porosity

Simulation 3: coupled flow and geomechanics with fixed porosity and time-dependent (changing) permeability

Simulation 4: coupled flow and geomechanics with both porosity and permeability changing with time

The model problem consisted of a single, 144-ft thick layer of Belridge Field diatomite located at a depth of 1188 ft. The layer is modeled as a square, 330 ft on each side, with a well at each corner. The wells are completed to different depths. The mechanical loading is gravity plus the transient pore pressure field. The IPARS grid contains 7938 cells while the JAS3D mesh has 42875 elements. The model problems were run for a simulation time of ten years with each calculation taking 90 minutes on a 400 MHz Sun workstation. The results clearly showed changes in the flow simulation pore pressure field due to dynamic porosity and permeability fields. Compaction caused decreased permeability that resulted in less flow (less fluid produced) as one would expect in such a highly compactible, low-permeability material as diatomite. These experiments served as initial checks on the dynamic permeability updates, but further validation is needed as the magnitude of these differences depends upon the exact relationship one uses to relate volume strain to porosity and permeability.

Semiautomatic System for Waterflood Surveillance (Aera Energy LLC, Atlantis Scientific, Chevron, Electromagnetic Instruments, Integrated Micro Instruments, and LBNL)

Report not received.

Drilling, Completion, and Stimulation Technology

Evaluation of Concepts and Components for Directional Underbalanced Drilling and Microdrilling

(DeepLook, Fleet Cementers, Maurer Engineering, Mobil, Texaco, U of Tulsa, and LANL)

Project in close-out phase.

Real-Time Coiled Tubing Inspection System

(Quality Tubing and INEEL)

Highlight:

- Hall probe system completed and used to test samples.

Coiled tubing stripping tests continue. Tubes were sent to the University of Tulsa for fatigue testing in November. Results are expected in mid-January.

Perforation Dynamics in Geological Media

(Columbia Gas Transmission, Halliburton, National Fuel & Gas Supply, Panenergy, and LLNL)

Highlight:

- Project presented at NGOTP review meeting.

A presentation was made before the NGOTP DCST Industry Review Panel in Houston, November 14. The presentation outlined proposed future work to be carried out over a two-year period by a joint team that consists of LLNL, Pennsylvania State University, and the Jet Research Center (JRC) Division of Halliburton Energy Services, Inc. JRC is offering to provide funding to match that of DOE.

Assuming acceptance of the proposal, the tasks to be performed will include (1) refining the fines migration and ablation model and validating with quantitative comparison with experimental data on Berea sandstone, (2) extending the model to harder and weaker sandstones and porous limestone, and performing X-ray CT experiments to measure fines distribution and permeability, and (3) deriving core flow efficiencies based on computer modeling and validating these with measurements to be made in API RP-43 flow tests. The degree of underbalance would be varied prior to perforating.

Drill Cuttings Injection Field Experiment

(BP Amoco, Chevron, Exxon, Gas Research Institute, Halliburton, Hughes Christensen, MSD, Pinnacle Technologies, Schlumberger, Shell, and SNL)

Highlight:

- Laboratory examination of fundamental mechanisms continues.

All of the field work for the project was completed in 1999. Final reports are being compiled on the tiltmeter results, the microseismic results, and calculations of the stress changes induced by the injection series. Laboratory work to examine some of the fundamental mechanisms continues, along with modeling of the lab results.

Seismic Stimulation for Enhanced Production of Oil Reservoirs

(AERA Energy LLC, Applied Seismic Research, Chevron, Conoco, Fluidic Technologies, Halliburton, Marathon, Oil and Gas Consultants Int'l., PerfClean, Phillips, Piezo Sona-Tool, Texaco, UC-Berkeley, LANL, and LBNL)

Highlights:

- Lost Hills stimulation field test continues.
- Laboratory two-phase flow experiment completed.

Chevron and Applied Research Corporation continue field testing of a downhole fluid pulsation device at the Lost Hills Diatomite reservoir in central California. An initial 12-day stimulation treatment, started in late July, produced an increase in oil cut and oil production for 20 monitored wells at distances of 200 to 2300 ft from the stimulation source. A similar increase was observed during the Hector Mine earthquake of October 1999. LBNL is awaiting well availability to monitor the seismic signals within 200 ft of the source as well the downhole pressure.

Laboratory two-phase flow experiments were completed on stimulated enhancement of oil and brine flow for different flow-rate ratios. The results indicate that stress stimulation causes water-wet rocks to trap oil. This implies reservoirs that are at least partially oil wet are likely candidates for stimulation, as the treatment may cause formation water to be trapped and thus increase the oil cut.

In-Well Imaging and Heating: Multiple-Use Well Design

(Aera Energy LLC, Chevron, SteamTech Environmental Services, and LLNL)

Highlight:

- Mapping system demonstrated.

The changes in electrical resistivity detected through imaging during stimulation can be interpreted in terms of fluid movement. During the initial monitoring phase, prior to temperature increase, individual pay units displayed consistent changes. Some units showed an increase in electrical resistivity; others a decrease. Interpreting these changes using Archie's Law with considerations given the reservoir characteristics based on independent data permit an estimate of fluid movement in the vicinity of the imaged volume. In the simplest interpretation, increasing resistivity can indicate oil displacing formation fluid in the pore space; decreasing resistivity indicates oil being removed from the pore space. These changes are consistent with the pressure support provided through the steam injection and production activities. Contributing factors include the resistivity of steam condensate, which may contrast with the native formation fluids. Initial evaluation during the ambient-temperature monitoring phase supports a net movement of oil out of the imaged zone perpendicular to the production well, which is consistent with production strategy. The ability to make such evaluations may have strong implications for reservoir management.

The LLNL/AERA team facilitated a field demonstration of the Water Technology mapping system to monitor steam flood in conjunction with the electrical imaging currently underway. Preliminary results have been discussed. Water Technology used a subset of the point electrode string during their survey. Unfortunately, a few of the electrodes were damaged during the survey, rendering them useless for future imaging work.

Work continues on the combined imaging/heating capability. The final ohmic heating simulations are being used to generate imaging models to evaluate the ability to image ohmic heating during the process using electrical resistivity tomography.

3D Analysis for Induction Logging in Horizontal Wells

(BP Amoco, Chevron, Conoco, Electromagnetic Instruments, Exxon, Halliburton, Mobil, Phillips, Schlumberger-Doll, Shell, Texaco, Unocal, Western Atlas, and SNL)

Highlight:

- Initial draft of SAND report completed.

An initial draft of a SAND report is complete. It documents tool sensitivity for dipping boreholes in horizontally stratified anisotropic formations. Final revisions and submission of the report are due early in 2001.

A graphical user interface was developed for the 3D finite difference code. Electrical models are described in terms of the conductivity of the formation in each of the three principle axes, as well as the Euler angles, relating the local principle axes reference frame to the global modeling reference frame.

A working inversion algorithm was developed for interpreting induction log data in terms the "bed-parallel" and "bed-perpendicular" electrical conductivities. The algorithm also interprets the angular orientation of the bedding planes to the model reference frame. The inversion procedure is based on the assumption that the data can be reasonably interpreted in a local sense by a uniformly conducting anisotropic wholespace.

A matrix-free implementation of the anisotropy code is under development in order to decrease memory requirements of the code.

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Chevron, INEEL, and LBNL)

Highlights:

- Feasibility report completed.
- Savoy Field Research Facility selected for prototype testing.
- Prototype constructed.

Data from the field tests of the downhole regenerative source and capacitive discharge sources were input into LabVIEW for plotting and preliminary analysis.

Acoustic Telemetry (MWD)

(ABB, Passband Downhole Communications, Electroacoustics Research Laboratory, and SNL)

Highlights:

- Integration of system software completed.
- Telemetry patents awarded.

With the exception of the revised power amplifier, all components of the telemetry prototype are complete. This includes all system software and hardware. Integration of system components is nearing completion. We expect to have a fully operational prototype before the end of the year.

Two additional acoustic telemetry patents were recently awarded to SNL. These patents cover critical assembly methods used in the prototype tool. In a previous report, a technical advance on repeater technology was mentioned. As a spin off of that work, SNL now knows how to improve the signal to noise in the prototype tool for this project by more than 12 dB. Potentially, this will increase the transmission range of our prototype by another 3000 ft even without using a repeater.

Development of Chemically Bonded Ceramic Borehole Sealants

(GPRI, ANL, and LANL)

Highlights:

- Kick-off meeting held.
- Testing of the ceramic borehole sealant initiated.
- Project presented at NGOTP review meeting.

A kick-off meeting was held on the collaborative research and development agreement (CRADA) project between ANL and GPRI. Nine cement experts from the GPRI member companies (Exxon-Mobil, Chevron, BP Amoco, and Shell) attended. A complete test matrix was developed for testing the borehole sealant at Chevron and ANL.

Following this meeting, the ANL principal investigator spent one week at Chevron's Cement Laboratories to perform initial API Standard tests. By adding a small amount of additive, pumping times were varied at different temperatures. More tests are under way to develop complete profile of pumping time, temperatures, and pressures. Slurry rheology was excellent, indicating that the slurry can be pumped easily. Fluid loss was also minimal. This small loss was due partly to the excess water that was added to the slurry. This will be reduced in future formulations. No free water was observed in the paste.

The project was presented at the NGOTP annual review. The presentation went well, and reviewers' comments were positive. Some suggestions were made regarding oil field applications of the technology. These suggestions will be incorporated during development of demonstrations for the borehole sealant.

The near-future program will involve more testing of this material at Chevron and ANL according to the test matrix developed in the kick-off meeting.

Coiled-Tubing Deployed Microdrilling with Real-Time, Downhole Monitoring (DeepLook, Fleet Cementers, Phillips, Texaco, and LANL)

Highlights:

- 600-ft drilling demonstration completed at the San Ysidro drilling site.
- Coiled-tubing deployed percussion drill used to drill a "hard" section.

San Ysidro Drilling Demonstration

A 1-3/4-in.-diameter hole was drilled to a depth of 270 ft with a 1-11/16-in single lobe motor and a polycrystaline diamond (PCD) bit. The hole bridged at 170-ft depth during a weekend shut down, and attempts to drill the bridge were unsuccessful.

The drilling rig was skidded 6-ft and a second hole was drilled. A "hard" spot was encountered at 178 ft, and various attempts to drill it with rotary PCD and diamond impregnated bits were unsuccessful. The 1-3/4-in. hole was reamed to 2-1/4 in., and a commercial, hydraulic, rotary-percussion motor was used to drill less than 1ft of hard rock.The hole was drill to a depth of 599 ft after encountering artesian water flows at 295 and 400 ft. The water flows could not be controlled during the night-time shutdowns, and significant hole enlargement was occurring. Drilling was suspended at 599 ft, and preparations to cement in a 1.66-inch OD PVC casing were completed. The first attempt to run PVC casing was suspended after encountering a bridge at 240 ft. An attempt to drill the bridge resulted in parting the coiled tubing.

A coring rig was mobilized to run BQ drill rods and remove the coiled tubing and the drilling assembly. The BQ rods were run to 599 ft, and the bit, drilling motor, and coiled tubing were successfully removed. A second attempt to run PVC casing reached a depth of 190 ft but was suspended after hitting bridges at 170 and 190 ft. The BQ drill rods were being run to TD as the month ended.

Instrumentation

Control System. The new hydraulics system performed well during the drilling demonstration. The interface with the PC (LabVIEW data acquisition and control software) control system was also demonstrated.

Downhole Sensor Sub. No activity to report.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation (Input/Output, Texaco, and LANL)

Highlights:

- Microhole drilled for array testing.
- Continuation proposals presented at NGOTP review meeting.

A microhole was spud and drilled to 600 ft for testing of the microhole seismic array preparatory to deployment in a commercial seismic survey. Casing, has yet to be inserted and cemented.The drilling of the microhole achieved two notable milestones. First, a percussion bottomhole assembly was adapted for use with the LANL microhole drilling system and then used to efficiently penetrate near-surface hard rock that was not penetrable using the current PDM-bit combination. Second, 1-3/4-in.-diameter microhole sections were drilled—the smallest diameter microhole drilled using coiled tubing to date.

Development of Single-Well Seismic Imaging Technology

(BP Amoco, Chevron, Conoco, Exxon, OYO Geospace, P/GSI, Phillips, Schlumberger, Shell, Texaco, TomoSeis, Unocal, Western Atlas, Stanford, LBNL, SNL, and INEEL)

Highlight:

- Poster papers prepared.

SNL continues to conduct computational simulations of the seismic reflections observed at the Bayou Choctaw Salt Dome test site. Recent efforts involve introducing anelastic effects, based on the standard linear solid formalism, into our 3D finite-difference wave propagation algorithm. Anelasticity is probably an important geophysical phenomenon at Bayou Choctaw, due to the fairly low quality factor (Q) values (for both compressional and shear waves) of Gulf Coast sediments. Preliminary modeling results indicate that anelasticity reduces the amplitudes of the computed salt flank reflections sufficiently so that they now agree reasonably well with the field-recorded data. However, incorporation of anelasticity into the wave propagation algorithm increases the computational burden (memory and execution time) substantially.

Two poster papers were prepared dealing with seismic wave propagation issues (anelasticity and reciprocity) for presentation at the annual Fall American Geophysical Union Meeting in San Francisco in December.

Large Downhole Seismic Sensor Array

(Chevron, Conoco, Exxon, OYO Geospace, Shell, Texaco, U of Arkansas, and INEEL)

Highlight:

- Construction of demonstration prototype begun.

The totally passive design is complete and will be tested in December as weather allows. The electronics package was removed from the demonstration coiled tubing segment and will be installed in the new prototype. Test results will be included in the final report.

Detailed drawings are nearly complete providing documentation of the more capable of the INEEL developed and tested module configurations. They will be provided as part of the output documentation from the project.

The final report draft is still out for continuing review.

Improved Prestack Kirchhoff Migration for Complex Structures

(Conoco, Cray/SGI, Golden Geophysical, Kerr-McGee, Mobil, Shell, and LANL)

Highlights:

- Migrations of numerical and field datasets investigated.
- Migrations using single phases conducted and assessed.

Previously, LANL completed migrations of numerical and field datasets using multiple-valued traveltime tables with and without amplitude and phase corrections calculated from ray tracing included in the migration operator. We are now migrating the same datasets using single valued traveltime tables where the single arrival used is selected based on some criteria. So far, we have investigated the following criteria: (1) earliest arrival, (2) most energetic arrival, and (3) shortest travel path arrival. We found that the most energetic and shortest path arrivals give better images than earliest arrival for the Gulf of Mexico subsalt numerical dataset. However, for the field dataset, the earliest arrival image is the best when amplitude and phase corrections are added to the migration operator. We believe that the earliest arrival operator works best for the field dataset because errors in the velocity model for the field dataset make the prediction of later arrival times incorrect. Therefore, the inclusion of later arrivals adds noise to the image rather than improving the image. We are working to investigate this conclusion.

Locating Geopressured Hydrocarbon Reservoirs in Soft, Clastic Sediments Through Identifying Associated Pressure Seals

(Conoco and INEEL)

Highlights:

- Invention disclosure reports submitted.
- Reservoir modeling completed.
- Synthetic modeling completed.

Three invention disclosure reports (IDRs) based on project work and a preliminary draft report detailing the results of the work were submitted. The invention disclosure records are titled:

Method for low-frequency seismic, sonic and infrasound detection of acoustic and geopressure transition zones.

1. Ahead-of-bit method for low-frequency seismic and infrasound detection of geopressure transition zones while drilling wells.
2. Method for using naturally occurring seismic amplitude or reflection strength variation with frequency boundaries for quality control of spectral balancing in geophysical seismic processing.

IDR's 1 and 2 protect intellectual property that demonstrate a method for locating geopressured hydrocarbon resources in young, active basins (e.g., Gulf of Mexico [GOM]) worldwide. These resources account for only 10% of the reservoirs in GOM, but more than 50% of cumulative production. Our studies have shown that pressure transition zones have a unique seismic frequency response when viewed with a low-frequency filter. Specific applications include oil and gas exploration (new reserves) and ahead-of-bit detection of anomalous pressure regimes (drilling safety and drilling cost).

IDR number 3 pertains to processing seismic survey data (used in oil and gas exploration and development). This process historically required operator judgment on the use of different frequency whitening filter to remove spurious noise from the dataset. Our studies on seismic processing of pressure transition zones, which account for more than 50% of cumulative oil and gas production in the Gulf of Mexico, have shown that we can use the different reflected frequency spectra between sharp and gradational acoustic contacts to estimate the best frequency filters for a given dataset. The benefit expected is to produce faster and more accurate imaging in seismic survey processing.

Testing Advanced Computational Tools for 3D Seismic Analysis Using the SEG/EAGE Model Dataset

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, Burlington Resources, Chevron, Conoco, Edison Chouest Offshore, Exxon, GECO-Prakla, Golden Geophysical, Kerr-McGee, Marathon, Mitchell Energy, Mobil, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Texaco, Union Pacific Resources, Unocal, Western Geophysical, Houston Advanced Research Center/Rice, Stanford, UC-Davis, U of Houston, LANL, LLNL, and ORNL)

Project is in close-out phase.

Integrated Reservoir Monitoring Using Seismic and Crosswell Electromagnetics

(Chevron, Electromagnetic Instruments, TomoSeis, LBNL, and SNL)

November was spent working on a paper for *Geophysics* entitled "Crosswell electromagnetic and seismic imaging: An examination of coincident surveys at a steam flood project." The paper is being written in collaboration with Texaco, whose personnel have contributed to the second draft. The paper is expected to be finished and submitted by the end of January, 2001.

Frequency-Dependent Seismic Attributes of Fluids in Poorly Consolidated Sands

(Baker-Atlas, Chevron, TomoSeis, Vastar, and LBNL)

Work during October and November focused on four efforts: (1) developing a closed-form expression that describes the effects of the jacket attenuation in our clad-rod tests, (2) modifications to our 3D cylindrical finite-difference code to include the effects of attenuation, (3) testing of our new combination extensional/torsional wave source, and (4) aluminum calibration tests using our new dynamic stress-strain apparatus.

In the first effort, we used the results of R.N. Thurston for clad rods (Journal of the Acoustical Society of America, 64 (1), 1-37, 1978) to obtain a low-frequency approximation for the effect of a viscoelastic jacket on fundamental mode extension, torsional, and flexural waves propagating in a jacketed sample. This expression will be used to analyze the effect of a plastic jacket on the attenuation of low-frequency waves propagating through a sand pack with low confining pressures.

The second development was the addition of attenuation in our 3D cylindrical, time-domain finite difference code. This modification used the memory variable formulation to allow the bulk and shear moduli to be described a superposition of relaxation mechanisms of the standard linear solid type. This code will be used, along with the low-frequency solution described above, to determine the effects of the plastic jacket in our tests as the confining pressures are reduced below 1000 psi.

In the third effort, we completed assembly of our combined extensional/torsional wave source. This new source is in the process of being tested on an acrylic bar. Prior tests that were conducted after the extensional/torsional stack of piezoelectric crystals were bonded together, but prior to assembly in the stainless steel housing, showed clean torsional and extensional wave generation in the 3 kHz range. The test being performed currently will determine the effects of the steel housing on the frequency response of the source over the 1–10 kHz range.

The last effort we are reporting here represents the first steps in our efforts to measure the viscoelastic properties of unconsolidated sands in the 1–100 Hz range. We assembled the electronics (lock-in amplifier, power amplifier), the sensors (piezoelectric force transducer, interferometric fiber optic strain gauge), and a piezoelectric actuator to allow us to dynamically excite samples while measuring their quasi-static stress-strain properties. We are in the process of preparing an aluminum calibration test to determine the characteristics of our system. If the calibration tests are successful, we will move forward to the next step of developing a methodology for embedding the fiber optic strain gauge sand packs.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, Conoco, Fairfield Industries, GX Technology, Marathon, Texaco, Unocal, and SNL)

Highlights:

- Industry participant meeting held.
- Project presented at NGOTP review meeting.

A meeting was held with the industry collaborators of this project at Fairfield Industries in Houston on November 14. Progress to date was summarized, and suggestions were gathered regarding presentation of the project status to the annual NGOTP DIT review panel on November 16, also in Houston.

Full waveform inversion of seismic data entails finding a subsurface earth model (represented by two elastic parameters and the mass density) that generates predicted seismic data that agree (to within an acceptable tolerance) with the observed seismic data. Extensive theoretical work during the past two months has involved deriving the precise mathematical form of a linearized updating equation for the subsurface earth model parameters, starting from the

reciprocity principle of elastodynamics. Implementation of this updating equation within an inversion algorithm in a parallel computational environment is currently in progress.

High-Speed 3D Hybrid Elastic Seismic Modeling

(Burlington Resources, GX Technology, and LBNL)

Highlights:

- Local boundary condition tested for handling of steep tomography models.
- Finite-difference schemes tested.

The local boundary condition approach was tested to see how well it handles steep topography models. By introducing extra grid nodes at intersections of the topography function and rectangular model grid LBNL achieved high stability of computations.This approach will be used for the 3D elastic algorithm.

Both second- and fourth-order in time finite-difference schemes were tested on the T3E and IBM massive parallel supercomputers located at the LBNL/ NERSC supercomputer facility. We measured changes in run times as the number of subdomains were increased, together with total model size and number of CPUs used. The T3E computer showed better performance compared to the IBM machine due to a more effective internal data flow and communication. The fourth-order time differencing scheme showed progressive improvement over the second-order scheme as the number of CPUs increased.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, Burlington Resources, Chevron, Conoco, Exxon, GECO-Prakla, Marathon, Mobil, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Texaco, Union Pacific Resources, Unocal, Western Geophysical, Stanford, U of Houston, LANL, and LLNL)

Highlights:

- Project presented at NGOTP review meeting.
- Plans to design new models with SEG sub-committee discussed.

The project was defended at the annual NGOTP industry review meeting in Houston. Start-up efforts and plans for the upcoming year were presented.

The SEG is forming a sub-committee to define the next generation models that will be tested with various numerical codes. The committee is currently seeking members to contribute this effort. The NGOTP project will participate actively in this. Plans for the initial meetings of this committee are being discussed with the committee chair.

Partnership Office

A major effort of DOE Fossil Energy is to develop an Ultra-deep Water Technology Initiative focused on increased production in the Gulf of Mexico (GOM). Industry seeks a better definition of how Partnership technologies address GOM problems. To facilitate this definition, DOE is setting up a special session at the Offshore Technology Conference in May 2001. The Partnership office has started preliminary determination of Partnership papers and projects to be highlighted at this session.